

Applications of Network Visualisation in Infectious Disease Management

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ABSTRACT

The SARS outbreak during the spring of 2003 showed that any new cases can trigger rapid community and non-social cluster transmission of SARS-CoV. This created substantial health, social and economic consequences. Improved outbreak management requires that identification of such diseases must trigger an immediate public health response. Rapid detection and management of infectious diseases such as SARS and their contacts together with the prompt implementation of the appropriate control measures can arrest and contain the transmission and spread of disease.

Given the likelihood and observed frequency of outbreaks of infectious diseases, there is a need to be able to detect, manage and control the disease transmission as early as possible and thus minimise the impact of the outbreaks. Effective public health surveillance can act as an early warning system by detecting microbial, environmental, behavioural, occupational, and other health threats. It can also concentrate resources, focus interventions and facilitate planning.

The issues and technological solutions for infectious disease management are also applicable to Chemical, Biological, Radiological and Nuclear (CBRN) threat domains as these all share many common factors.

This paper aims to discuss the use of and need for visualising the network of interconnected information for situation awareness to assist in taking effective control measures during infectious disease outbreaks.

INTRODUCTION

The outbreak of SARS (Severe Acute Respiratory Syndrome) triggered the current, critical examination of information systems. Questions arise regarding the quality, type and availability of critical data. The ability of organisations to generate and communicate information has also come under discussion. The level of preparedness and the ability of the health community to respond to unexpected large or even small events remain topics of concerns [1].

The relevant information to be managed for disease control can be said to form a Network of Information. That is a large number of different but related or connected items of information from a variety of sources and in a variety of locations or systems, e.g. availability of hospital beds, vaccine use, outbreak locations, age groups and mortality etc.

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There is a need for a framework that is able to manage comprehensively and cohesively the network of disease information, provide facilities to analyse the available data and information and communicate the resultant information to relevant bodies/users so that effective control measures can be defined, implemented, managed and monitored to control or contain transmission and spread.

To be fully effective this requires a single network of information that functionally and organisationally integrates all relevant partners across the country.

In summary, the goal of a disease surveillance programme is to be able to monitor and assess disease trends, i.e. provide **situation awareness**, and use this information to guide prevention and intervention programmes. In addition, to inform public health policy and policy makers and protect confidentiality as well as providing, presenting and **visualising the network of information** to those who need to know.

SITUATION AWARENESS

Situation awareness is essential for effective decision making.

There are many definitions of situation awareness, different domains and communities define it differently. The following are some definitions:-

“The understanding of the situation gained from the sum total of the relevant information provided to make a correct decision regarding the allocated objectives and/or the desired end state.” [2]

“Situation awareness is the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future.” [3]

Situation awareness has been studied for many years in many domains. In the dangerous environment that is common to:

- Outbreak of infectious disease,
- Chemical, biological, radiological and nuclear threats;
- Emergency;
- Nuclear power;
- Aviation;
- Military and other domains;

there is a requirement to make decisions in high stress environments with significant uncertainty, time pressure and often with lives at stake [4]. In such complex environments strong situation awareness can greatly improve the rate and the quality of human decision making.

The results of the situation assessment assist in developing a mental model which represents our situation awareness. This mental model is a representation of the environment and its expected behaviour. The model is used to provide the conceptual framework for describing, explaining and predicting future system states.

True situation awareness will be made possible by a diverse set of information and telecommunications technologies interoperating in a coordinated fashion. It can only be achieved through major advances in the national health/disease information infrastructure [4].

APPLICATION OF NETWORK VISUALISATION

The above shows that a complex network of data is collected for various purposes and from which it is important that relevant and credible information is extracted, analysed and collated with other information to assist in decision making. Often the information items are dynamic, diverse and can be tightly or loosely correlated, however, together they provide the essential support to make informed decisions, for example, to control the spread of the infectious disease or to halt CBRN threats. These complex information networks, however, represent an information overload to the user/decision maker [5]. The concern must be how to alleviate this overload, and network visualization provides the solution.

Formally, network data refers to items called nodes that have relationships (links) to an arbitrary number of other items/nodes. Nodes and links can have a variable number of attributes.

The attributes and relationships between items can be very complex. The internet, for instance, consists of tens of thousands of servers with numerous possible paths between them. Attempting to understand internet traffic patterns, peaks and troughs of usage, and alternative paths between nodes by looking at tables and statistics is only possible for very limited tasks. Visualisation provides a means of addressing this problem [17].

The concept of network visualisation is to present (or visualize) the structure of a network and its associated data in an effective way so that vital information can be extracted, analysed, understood and applied in a timely manner. Thus, the goal of network visualisation is to enable the user to gain insight into a structure that may consist of many data items.

There are many categories of networks, e.g. acyclic, lattice, rooted versus un-rooted, directed versus undirected. This categorisation enables researchers to develop algorithms to perform tasks on these structures, such as finding the shortest or least cost paths connecting two items or traversing the entire network.

Large sets of data tend to have much of their information hidden. Finding a structure hierarchy among a set of data points is not easy. Much of the early work on visualization came from graph drawing. A graph with few points or vertices is easy to draw and to comprehend visually, but tools are needed to manage large data sets.

The most straightforward way to illustrate a network is a 2-dimensional or 3-dimensional diagram. Some visualisation techniques add animation, distortion and tightly coupled overview windows to reveal additional information about a network.

The effectiveness of the network visualisation usually depends on the size of the network, understanding of the information required from the network and the user's expectation. In the case of small networks it is possible to focus on detailed elements of the graph structure while in the case of large networks only gross topology can be captured. Visualisation of networks with thousands of nodes requires abstraction [17].

The presentation of the topology features of the graph help to facilitate comprehension and usability. For example, edge crossing, running edges 'under' nodes that are not connected to each other and stacking nodes on top of each other all hinder comprehension and use of the graph [8]. Colour, size and shape are always useful ways to increase comprehension and add additional information on relational attributes.

Applications of Network Visualisation in Infectious Disease Management

There are a number of on-going and active network visualisation efforts and programmes (academic and commercial), many of which focus on the internet and related components.

Graphical network maps have also been used for many years in commercial network management products designed for enterprise networks. Network managers use these graphical interfaces to monitor an enterprise's computer network and access software functions to troubleshoot and fix network problems. Network visualisations can also be used for transport management, or the many interconnected components of software code.

SOCIAL NETWORK ANALYSIS AND INFECTIOUS DISEASE

There are healthcare-related tasks that could benefit from the use of network visualisation; such as social networks.

Social networks are used to study a variety of different social aspects, for example, effects on the spread and possible containment of multiple, interacting disease causing organism. The network can be used to model how social contacts might change in response to an outbreak or to intervention strategies. Many diseases spread through human populations between infective individuals and susceptible individuals. The pattern of these disease causing contacts (physical or otherwise) forms a network. This contact network can be used as a mathematical model for the spread of an infectious disease and provides a possible means of quantifying important spreading information such as the conditions under which a large outbreak is possible, probability of such outbreak and the size of the outbreak if it occurs.

A useful model for social networks is to represent social distance as physical distance. This representation allows users to get a spatial understanding of social relations; nodes with many relations in common are placed close together in a representation (visualization). An intuitive impression of network structure then emerges from the proximities in the visualization image. For example, one can easily see racial segregation in network visualization as the clustering of races into distinct spaces on the display [9 -17]. A social distance-based representation of network structure is facilitated when edge lengths are equated to relational strengths. There are various force-directed layout techniques which are usually successful at this.

NETWORK VISUALISATION TOOLS

There are various commercial and free software tools available for the analysis of social networks. Some of the tools are targeted at visualization of networks only, while others contain analysis procedures only: there are also packages which integrate network analysis and visualization. The software available include: UCINET, Pajek, NetMiner, STRUCTURE, NetDraw, MultiNet, StOCNET, SNAFU, InFlow, NetVis, Visone, PGRAPH, etc.

CONCLUSIONS AND RECOMMENDATIONS

The visualisation techniques described in this paper show that there are many ways information visualisation can help users access information more effectively. Visualisation systems enable users to examine large amounts of complex data and quickly find the required information, navigate and interact with data more easily, recognise patterns and trends and to obtain a better understanding the information.

A wide variety of network visualisation tools have been developed specifically or can be adapted for health related tasks. However, none of them provide the capabilities that encompass all the requirements for managing the dynamic and unpredictable scenario of detecting, monitoring and managing the possible outbreak of infectious disease.

Much work is still required to develop an infectious disease network visualisation tool that can manage the dynamic and unpredictable nature of any potential infectious disease outbreak or CBRN threats.

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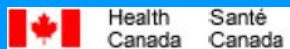
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Introduction

Outbreak of SARS triggered the current critical examination of information systems

A network of different information from different sources and systems was generated during the outbreak.

E.g. outbreak locations, age groups, mortality, hospital beds, vaccine, isolation, etc.

SARS

Late November 2002

- Emerged in the southern Chinese province of Guangdong

Late February 2003

- Worldwide epidemic was triggered
- Ill physician from Guangdong infected several other guests at a Hong Kong hotel
- These infected people became the index patients for large outbreaks of SARS in Hong Kong, Vietnam, Singapore and Canada

12th March 2003

- WHO issued a historic global alert for SARS

5th July 2003

- Official end of the global health emergency

Rapid spread of the disease and high levels of morbidity and mortality shows the need for careful monitoring for the re-appearance of SAR or other diseases

Questions Raised

Quality, type and availability of critical data ?

Ability of organisation to generate and communicate information to relevant organisations ?

Level of preparedness and the ability of health community to respond to unexpected large or small events ?

A possible solution

Framework to manage comprehensively and cohesively the network of disease information

Provides facilities to analyse the available data and information

Present the resultant information to relevant bodies and users

A single network of information that functionally and organisationally integrate all relevant partners across the country

Infectious Disease Management Programme

- Monitor and assess disease trends: **situation awareness**
- Guide prevention and intervention programmes
- Inform public health policy and policy makers
- Protect confidentiality
- Provide, present and **visualise the network of information** to all the players

Situation Awareness

- Plays a significant role in effective decision making
- *Assists in developing a mental model of the situation*
 - *Representation of the environment and its expected behaviour*
- *Produces a network of information:*
 - *Describes and explains the current situations*
 - *Predicts the future*
- *Needs a tool to visualise the generated network of information*

Network Visualization

Present the structure of the network and its associated data in an effective way so that vital information can be:

- Extracted
- Analysed
- Understood
- Collated with other information

Information can be:

- Dynamic
- Diverse
- Sporadic
- Tightly or loosely correlated
- Credible
- Unavailable

Network Visualization

Visualize the data associated with a network

- Understand data, not network themselves

Coping with large data volumes

- Hundreds of nodes
- Thousands of links
- Data from time periods

Network Examples

Network	Nodes	Links
Disease	Locations	Routes
WWW	Webpages	a link between them
Aviation system	Airports	direct flight
Football game	Players	Movements

Network Visualization

Use:

- Colour
- Size
- Shape
- Symbols
- Animation
- Sounds
- etc.

Social Networks

Individuals interact in networks and spread diseases within the networks

Many diseases spread through human populations between ineffective individuals and susceptible individuals, e.g. SARS

The pattern of these disease causing contacts, air borne, water borne form a contact network

- Quantify spread information, e.g. conditions under which a large outbreak is possible
- Probability of outbreak
- Predicted size of outbreak

Integration of Networks of Information

Different sources of information:

- Contact Information
- Outbreak Information
- Disease Trend Analysis
- Others, e.g. hospital beds, diagnostic tests, treatment, budgets, economic impacts, etc.

How to integrate all of them to create a single network of information that functionally and organisationally integrate all relevant partners across the country

Conclusions and Recommendations

Many available network visualisation approaches available

- Enable users to examine large amounts of complex data
- Find the relevant information quickly
- Navigate and interact with data
- Recognise patterns and trends to obtain better understanding of the information

Wide variety of network visualisation tools have been developed for:

- general purposes
- specifically
- Adapted for health related tasks

None of them encompasses all the requirements for managing the dynamic and unpredictable scenario of detecting, monitoring and managing the possible outbreak of infectious disease

Much work is still required to develop an infectious disease network visualisation tools that can manage the dynamic and unpredictable nature of any potential infectious disease outbreak or CBRN threats